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RESEARCH MEMORANDUM

EFFECT OF FUEL PROPERTIES ON CARBON DEPOSITION IN
ATOMIZING AND PREVAPORIZING TURBOJET COMBUSTORS

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUMEFFECT OF FUEL PROPERTIES ON CARBON DEPOSITION IN
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By Jerrold D. Wear and William P. Cook

SUMMARY

Investigations of the effects of fuel properties on combustion-chamber carbon deposition were conducted in single tubular fuel-atomizing and fuel-prevaporizing combustors. The relations of the NACA K factor, the smoking tendency, and a function of smoking tendency and volumetric average boiling temperature to carbon deposition were studied with several fuels varying in chemical and physical properties. The independent effects of increased sulfur, gum, and olefin content of fuels of similar NACA K factor were also studied.

The NACA K factor and the smoking tendency were approximately equally effective in relating carbon-deposition data from the prevaporizing and the atomizing combustors. A function of smoking tendency and volumetric average boiling temperature best correlated the carbon-deposition data obtained in the prevaporizing combustor. This function was somewhat less satisfactory for the data obtained in the atomizing combustor.

Increase in the sulfur content of a JP-3 fuel (MIL-F-5624A) by addition of disulfide oil or mixed butyl mercaptans slightly increased carbon deposition. A maximum increase of 38 percent with reproducibilities of 18 and 9 percent was observed with an increase in sulfur content from 0.38 to 1.40 percent by addition of disulfide oil. Increasing the gum content of JP-3 fuel to at least five times the maximum allowed by specification MIL-F-5624A was possible before an appreciable increase in carbon deposition was obtained. Increasing the bromine number of a JP-3 fuel from 12 to 54 by the addition of olefins had no effect on carbon deposition. It is concluded that only very large increases in gum or sulfur content of a fuel will cause significant increases in carbon deposition that will not be predicted by the NACA K factor.

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INTRODUCTION

Severe carbon deposition in the combustion chambers of turbojet engines may adversely affect certain performance characteristics of the engine, such as ease of ignition, combustion efficiency and stability, and durability. Carbon deposition at constant combustor conditions is dependent upon two factors: combustor design (including fuel injection and ignition) and choice of fuel. The results of a previous investigation (reference 1) indicate that carbon deposition tends to increase with the use of fuels with decreasing volatility and increasing aromatic content. One method of limiting the objectionable deposition is the control of pertinent fuel properties by fuel specifications.

Investigations have been conducted to determine the relative importance of various fuel factors affecting carbon deposition. The data of references 1 to 3 indicate that with annular- and tubular-type fuel-atomizing combustors, carbon deposition can be related to a function of the hydrogen-carbon ratio and the volumetric average boiling point of the fuel (NACA K factor). A function of "smoking tendency," as measured with a simple wick lamp, and average boiling point of the fuel has also given satisfactory predictions of carbon deposition in a fuel-atomizing annular combustor (reference 4).

A summary of a substantial amount of carbon deposition data obtained in atomizing combustors is presented in reference 5 and shows the relation of the data to NACA K factor, smoking tendency, volatility, gravity, and hydrocarbon type.

Fuel factors, other than those studied in these investigations, which may effect carbon deposition are sulfur, gum, and olefins. The investigation reported in reference 6 shows that the addition of disulfide oil to straight-run kerosene both increased and decreased carbon deposition depending on the simulated engine conditions which were used. The data from another investigation (reference 7) show that disulfide oil added to a JP-3 fuel increased and the addition of thiophene decreased carbon deposition. The results of the investigations reported in references 6 and 8 to determine the effect of gum content of fuels on carbon deposition indicate, in most cases, an increase in deposition with increase in gum. The data of reference 9 indicate that a large change in olefin content has a negligible effect on carbon deposition.

All investigations that have been considered used fuel-atomizing combustors. Since several current turbojet-engine models utilize fuel-prevaporizing combustors, the extension of carbon-deposition studies to this type of combustor was considered desirable.

Investigations were conducted at the NACA Lewis laboratory to determine the effects of sulfur, gum, and olefins on carbon deposition either in the fuel-atomizing or in the fuel-prevaporizing single tubular combustor or in both combustors. Data were obtained with MIL-F-5624A grade JP-3 fuels enriched in sulfur content by the addition of disulfide oil and mixed butyl mercaptans. High-boiling olefin residue and olefin distillate were used to increase the gum and olefin contents of the fuels. In addition, fuels of widely different properties (MIL-F-5624A grade JP-3 and JP-4, diesel fuel, and a pure aromatic fuel blend) were tested in either or both combustors. The fuels were tested in each combustor at similar combustor operating conditions.

The results of these investigations are presented herein to indicate (1) the applicability of the NACA K factor and "smoking tendency" to the prediction of carbon deposition in both fuel-atomizing- and fuel-prevaporizing-type combustors; and (2) the independent effects of sulfur, gum, and olefin content of fuels on carbon deposition obtained either in the fuel-atomizing- or in the fuel-prevaporizing-type combustor or in both combustors.

APPARATUS AND PROCEDURE

Fuel-atomizing combustor. - The investigations were conducted in a J33 single combustor described in detail in reference 2. Combustor operating conditions are presented in table I.

The liner, the liner dome, and the ignition plug were cleaned with motor-operated wire brushes and weighed before each run. The fuel nozzle was also cleaned. After the period of operation at the desired conditions with the test fuel, the liner, the liner dome, and the ignition plug were again weighed. The increase in weight plus the carbon scraped from the fuel nozzle was considered to be the total weight of carbon deposited. The clean assembly weighed approximately 2400 grams. Two or more runs were made with each fuel.

Fuel-prevaporizing combustor. - The combustor liner and the dome from a fuel-prevaporizing-type combustion chamber used for the investigations reported herein are shown in figure 1. Fuel is transversely injected into the air stream of the vaporizer inlet-air scoop through four equally spaced 3/64-inch-diameter holes, and the fuel and air mixture is conducted into the vaporizer through a tangential entrance passage. A small auxiliary tube in the vaporizer passageway directs air to the inside center of the vaporizer to minimize carbon formation. The vaporizer outlet is directed upstream and the vaporized fuel and air mixture is ignited by a flame-throwing spark plug located in the center of the combustor liner dome.

The combustor assembly was installed in the laboratory facilities in a manner similar to that used for the atomizing combustor (reference 2).

Combustor operating conditions used for the investigations are presented in table I.

The liner and the dome were cleaned by a vapor blast and weighed. After the run was completed at the desired conditions with the test fuel, the liner and the dome were again weighed. The increase in weight was considered to be the total weight of carbon deposited. The clean assembly weighed approximately 2100 grams. Two or more runs were made to give an indication of the reproducibility.

FUELS

The laboratory inspection data of the fuels used in this investigation are presented in table II.

The effect of sulfur was investigated by adding disulfide oil or mixed butyl mercaptans to low-gum JP-3 fuel (MIL-F-5624A). These sulfur compounds had the properties shown in the following table:

	Disulfide oil (extracted from petroleum distillates)	Mixed butyl mercaptans
Initial boiling point, °F	284	164
50 percent recovered, °F	324	190
Final boiling point, °F	414	308
Specific gravity	^a 0.968	^b 0.835
Sulfur, percent by weight	43	-----
Mercaptan sulfur (-SH), percent by weight	-----	37.7
Mixed butyl mercaptans, percent by volume	-----	67
Total mercaptans, percent by volume	-----	98

^a60°/60° F.

^b70°/60° F.

The effect of gum was investigated by adding to a low-sulfur JP-3 fuel either a small amount of plus 500° F residue from the distillation of an almost pure olefin stock or by adding substantial amounts of a 300° to 550° F overhead fraction of this stock. Portions of the olefin overhead fraction or distillate were brought to different levels of oxidation by passing oxygen through the fuel for different lengths of time. This procedure produced changes in the final gum content of the blend without significant changes in other fuel properties.

The effect of olefin content of a fuel on carbon deposition was determined by adding different amounts of the previously mentioned unoxidized olefin distillate to a JP-3 fuel of low gum and sulfur content. The bromine number is used herein as an indication of the olefin content.

The following groups of fuels were selected to determine the effects of NACA K factor, smoking tendency, sulfur, gum, and olefin on combustor deposits:

NACA K Factor and Smoking Tendency

Fuel number	Fuel	NACA K factor	Smoking tendency
51-86	MIL-F-5624A grade JP-3	264	----
51-186	MIL-F-5624A grade JP-3	257	8.3
50-264	MIL-F-5624A grade JP-3	331	18.6
51-201	MIL-F-5624A grade JP-4	306	10.8
51-306	MIL-F-5624A grade JP-4	326	16.7
50-105	Diesel	376	15.6
49-224	Pure aromatic	466	64.0

Sulfur

Fuel number	Fuel	Total sulfur (percent by weight)
50-264	MIL-F-5624A grade JP-3	0.38
51-205	50-264 plus 2.3 percent of disulfide oil	1.40
48-279	MIL-F-5624A grade JP-3	.04
48-393	48-279 plus 1.1 percent of disulfide oil	.55
48-361	48-279 plus 2.3 percent of disulfide oil	1.03
49-162	MIL-F-5624A grade JP-3	.04
50-122	49-162 plus 2.8 percent of mixed butyl mercaptans	1.05

Gum

Fuel number	Fuel	Gum (mg/100 ml)	
		Air-jet residue	16 hr accelerated
50-264	MIL-F-5624A grade JP-3	9	12
51-228	50-264 plus 1.8 percent of plus 500° F olefin residue	95	103
49-71	48-279 plus 21.3 percent of 300-550° F olefin distillate	7	12
49-125	48-279 plus 21.3 percent of lightly oxidized 300-550° F olefin distillate	77	445
49-143	48-279 plus 21.3 percent of medium oxidized 300-550° F olefin distillate	165	560
49-65	High aromatic, high olefin	5	337

Olefin

Fuel number	Fuel	Bromine number
48-279	MIL-F-5624A grade JP-3	12
49-71	48-279 plus 21.3 percent of 300-550° F olefin distillate	32
49-72	48-279 plus 46.2 percent of 300-550° F olefin distillate	54

RESULTS AND DISCUSSION

The results of the carbon-deposition runs in the fuel-atomizing and fuel-prevaporizing combustors are presented in table II. The results of the individual runs, the average value of carbon deposition for each fuel, and the arithmetical average percentage variation of individual runs from the average value are listed. The average percentage variation will hereinafter be called reproducibility.

NACA K Factor

The quantities of carbon deposited by various fuels that were investigated in the atomizing and prevaporizing combustors are plotted

in figure 2(a) against the NACA K factor. The K factor, developed in reference 1, is a function of volumetric average boiling temperature and hydrogen-carbon ratio of a fuel. The left side of figure 2(a) is a plot of this function and is presented in order to facilitate the determination of the K factor of the various fuels.

2464 The data obtained in the atomizing combustor indicate the expected increase in carbon deposition with an increase in K factor. The data obtained in the prevaporizing combustor indicate a similar relation between K factor and carbon deposition. The average deviation of the data points from the faired curve is approximately 10 percent for the atomizing combustor and 25 percent for the prevaporizing combustor. The corresponding average reproducibility for the fuels shown in figure 2(a) (table II) in each combustor was 10 and 17 percent, respectively. If the large average reproducibility of the carbon-deposition data obtained in the prevaporizing combustor is considered, the NACA K factor appears to apply equally well to both combustors.

Smoking Tendency

Data showing the relation of smoking tendency $320/h$ (where h is the maximum smoke-free flame height in mm) and carbon deposition for five fuels in the atomizing combustor and four fuels in the prevaporizing combustor are given in figure 2(b). A good linear relation is shown for the atomizing type with an average deviation of 11 percent from the faired curve. The average reproducibility for the fuels was 10 percent. A much poorer agreement is observed for the prevaporizing combustor with a reversal of trend between fuels 50-105 and 50-264. The average deviation is 21 percent with an average reproducibility of 13 percent.

A function of smoking tendency and volumetric average boiling temperature (reference 4) is used to correlate the carbon-deposition data in figure 2(c). The value of the function is obtained from the left side of the figure and is the ordinate plotted against carbon deposition. Somewhat better results are obtained for the prevaporizing than for the atomizing combustor by the use of this function. The average deviations are 7 and 14 percent, respectively.

The following table presents a comparison of the correlations obtained with the NACA K factor and the smoking tendency data:

Correlation function	Combustor					
	Fuel prevaporizing			Fuel atomizing		
	Number of fuels	Average deviation from faired curve (percent)	Average reproducibility (percent)	Number of fuels	Average deviation from faired curve (percent) (a)	Average reproducibility (percent)
NACA K factor	5	25	17	5	10	10
Smoking tendency	4	21	13	5	11	10
Function of smoking tendency and volumetric average boiling temperature	4	7	13	5	14	10

^aOnly the data plotted on fig. 2 were used for fairing the curves, which differ somewhat from the curves of figs. 3(a), 9(a), and 10(b) of reference 5.

The function of smoking tendency and volumetric average boiling temperature of fuels gave the best correlation for the limited carbon-deposition data obtained in the prevaporizing combustor. This function gave the poorest correlation for the atomizing combustor, although all three correlations presented may be considered satisfactory for this combustor.

Effect of Prevaporizing Combustor Operating Conditions

One fuel (50-264) was investigated at two simulated altitude conditions in the prevaporizing combustor for engine conditions A and B (see table I). The average deposit weights were 2.1 and 1.6 grams, the lower value being obtained at the higher simulated altitude (lower pressure) condition. This result is in agreement with that reported in references 1 and 2 for atomizing combustors.

Sulfur

Fuels, sulfur contents, carbon-deposition weights, and percentage reproducibility for both the prevaporizing and the atomizing-combustor investigations are presented in the following table:

Combustor type	Engine condition	Fuel	NACA K factor	Sulfur (percent by weight)	Average carbon deposition (grams)	Average reproducibility (percent)	Increase in carbon weight (percent)
	(a)					(b)	
Fuel prevaporizing	A	50-264	331	0.38	2.1	18	Base
	A	51-205	331	1.40	2.9	9	38
Fuel atomizing	D	48-279	347	0.04	7.0	5	Base
	D	48-393	347	.55	8.8	3	26
	D	48-361	347	1.03	8.4	4	20
	E	48-279	347	.04	20.2	6	Base
	E	48-393	347	.55	21.7	.3	7
	E	48-361	347	1.03	22.5	3	11
	F	49-162	345	.04	5.6	5	Base
	F	50-122	345	1.05	6.5	3	16

^aTable I.

^bTable II.

The addition of disulfide oil to increase the sulfur content of a JP-3 fuel caused increases in carbon deposition in both the prevaporizing and the atomizing combustors. The maximum increase in carbon deposition was 38 percent for the prevaporizing combustor and 26 percent for the atomizing combustor with sulfur increases of about 1 and 1/2 percent, respectively. Mixed butyl mercaptans, when added to a high-aromatic JP-3 fuel to increase the sulfur content from 0.04 to 1.05 percent (fuel 50-122), caused an increase in carbon deposition of 16 percent in the atomizing combustor. The percentage increase in carbon-deposition weights with the increase in sulfur content was somewhat greater in all cases than the average percentage reproducibility of the carbon-deposition data for any fuel. It appears unlikely that fuels meeting the present specification MIL-F-5624A maximum sulfur content of 0.4 percent would show anything except minor increases in carbon deposition attributable to sulfur. Increases in sulfur content to two or three times that permitted by the present specification would probably give increases in carbon deposition not predicted by the NACA K factor.

Gum

Fuels, gum contents, carbon-deposition weights, and percentage reproducibilities for both the prevaporizing- and atomizing-combustor investigations are presented in the following table:

Combustor type	Engine condition	Fuel	NACA K factor	Bro-mine number	Gum (mg/100 ml)		Average carbon deposition (grams)	Average reproducibility (percent)	Increase in carbon weight (percent)
					Air-jet residue	16 hr accelerated			
	(a)							(b)	
Fuel prevaporizing	A	50-264	331	8	9	12	2.1	18	Base
	A	51-228	331	--	95	103	2.6	12	24
Fuel atomizing	G	49-71	342	32	7	12	12.6	10	Base
	G	49-125	340	30	77	445	14.7	6	17
	G	49-143	344	25	165	560	15.4	14	22
	G	49-65	345	67	5	337	15.4	9	----

^aTable I.

^bTable II.

The air-jet and the accelerated-gum contents of fuel 50-264 were increased to 95 and 103 milligrams per 100 milliliters of fuel, respectively, (51-228) by the addition of high-boiling olefin residue. The large increase in gum content caused an increase in carbon deposition of 24 percent in the prevaporizing combustor. However, this apparent increase was accompanied by average reproducibilities of the carbon determinations of 18 and 12 percent.

The base fuel 49-71 used in the atomizing combustor was a JP-3 fuel blended with 21.3 percent of olefin distillate, and had a low gum content. Mild oxidation of the olefin distillate stock before blending with the JP-3 fuel raised the gum content of the blend (49-125) to 77 milligrams by the air-jet method and to 445 milligrams by the accelerated method. The carbon-deposition increase in the atomizing combustor was 17 percent above fuel 49-71 with 10 and 6 percent average reproducibility of the deposition data. Further increase in the gum content to 165 milligrams air jet and 560 milligrams accelerated (49-143) resulted in a carbon-deposition increase of 22 percent above that obtained with 49-71.

Carbon-deposition data for fuel 49-65 are included to compare a fuel of different composition but similar NACA K factor. This fuel, with a low air-jet gum and a high accelerated gum value, produced carbon deposits comparable with those obtained with the other high accelerated gum fuels.

Thus, with fuels of comparable NACA K factors, carbon deposition in both prevaporizing and atomizing combustors was increased somewhat by increasing gum content. However, increases in gum content of at least five times the maximum allowed by the present specification MIL-F-5624A (10 and 20 mg/100 ml for air jet and accelerated, respectively) were possible before the increase in carbon deposition was appreciably greater than that predicted by the NACA K factor.

Olefin

Fuels, bromine numbers, carbon-deposition weights, and percentage reproducibilities for the atomizing-combustor investigations are presented in the following table:

Engine condition (a)	Fuel	NACA K factor	Bromine number	Average carbon deposition (grams)	Average reproducibility (percent) (b)	Change in carbon weight (percent)
G	48-279	347	12	13.2	14	Base
G	49-71	342	32	12.6	10	-5
G	49-72	336	54	13.3	9	1

^aTable I.

^bTable II.

The NACA K factor of the fuels decreased slightly as the bromine number was increased from 12 to 54 by adding olefins (approximate olefin content change from 5 to 49 percent). Because the change in carbon deposition was less than the reproducibility, it is concluded that a change in the olefin content of a fuel has a negligible effect on carbon deposition.

General Observations

The carbon deposits in the fuel-prevaporizing combustor collected around the rim at the open end and on the outside bottom (fig. 1(b)) of the vaporizer with all fuels. With the pure aromatic fuel (49-224), the carbon deposits collected also on the inside liner wall.

No special difficulty was encountered with the prevaporizing combustor using high-sulfur and high-gum fuels. The bottom of the vaporizers of two different liners cracked during the runs; however, these liners had been previously used in other test rigs.

The carbon deposits collected around the inside of the dome and the upstream end of the liner in the atomizing combustor (fig. 3). There was no noticeable effect on the liners by the high-sulfur and high-gum fuels.

RESULTS AND CONCLUSIONS

Investigations of the effects of fuel properties on combustion-chamber carbon deposition of several fuels in single fuel-prevaporizing and fuel-atomizing tubular combustors indicated the following:

1. The NACA K factor and smoking tendency gave reasonably good correlations of carbon-deposition tendencies of the fuels and were approximately equally effective for both types of combustor; average deviations from the faired curve of 25 and 10 percent for the K factor and 21 and 11 percent for the smoking tendency were observed for the prevaporizing and the atomizing combustors, respectively.
2. A function of smoking tendency and volumetric average boiling temperature correlated carbon-deposition characteristics of fuels in the prevaporizing combustor the best, with an average deviation from a faired curve of 7 percent. This function was somewhat less satisfactory than either the NACA K factor or the smoking tendency for data of the atomizing combustor.
3. Increasing the sulfur content of a JP-3 fuel, without altering the NACA K factor, by additions of either disulfide oil or mixed butyl mercaptans slightly increased carbon deposition in both the prevaporizing and the atomizing combustors; the largest increase in carbon deposition, 38 percent (18 and 9 percent deposition reproducibilities), was observed with an increase in sulfur content from 0.38 to 1.40 percent.
4. Increasing the gum content of JP-3 fuel at least five times the maximum allowed by the present specification MIL-F-5624A was possible before an appreciable increase in carbon deposition was obtained in either the prevaporizing or the atomizing combustor.
5. Increasing the bromine number of a JP-3 fuel from 12 to 54 by the addition of olefins had no effect on carbon deposition in the fuel-atomizing combustor.

6. Apparently only very large increases in sulfur or gum content of a fuel will cause significant increases in carbon deposition that will not be predicted by the NACA K factor.

7. The prevaporizing combustor showed a trend of reduced carbon deposition with increased simulated altitude previously observed with atomizing combustors.

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TABLE I - COMBUSTOR OPERATING CONDITIONS



Combustor type	Engine condition	Run time (hr)	Inlet-air			Fuel flow (lb/hr)
			Flow (lb/sec)	Total pressure (in. Hg abs)	Temperature (°F)	
Fuel pre-vaporizing	A	6	2.87	53.9	271	127.0
	B	6	1.32	24.0	246	65.0
Fuel atomizing	C	4	2.87	53.9	271	127.3
	D	2	2.87	53.9	271	126.8
	E	6	2.87	53.9	271	126.8
	F	2	2.87	53.9	271	124.3
	G	4	2.87	53.9	271	124.3

TABLE II - FUEL ANALYSES AND CARBON-DEPOSITION RESULTS

NACA fuel	A.S.T.M. distillation (°F)					Volumetric average boiling temperature (°F)	Gravity (°A.P.I.)	Aromatics (percent by volume)	Bro-mine (percent by weight)	Sulfur (percent by weight)	Run (mg/100 ml)		Smoking tendency 520/h	Hydrogen-carbon ratio	NACA K factor	Carbon deposition (grams)				Engine condition (d)		Average reproducibility (percent) (e)			
	Percent evaporated										Air-jet residue	16 hr accelerated				Run				Fuel-pre-vaporizing combustor	Fuel-atomizing combustor	Fuel-pre-vaporizing combustor	Fuel-atomizing combustor		
	10	30	50	70	90											1	2	3	4					Average	
								(a)					(b)		(c)										
51-508	210	279	345	412	485	346	47.8	25	7	---	8	18	16.7	0.156	325	9.0	10.0	7.5	8.8	8.8	-	C	---	6	
51-186	177	234	294	358	433	299	55.8	10	.6	0.10	1	5	8.3	.171	257	5.5	5.2	5.8	5.4	5.4	-	C	---	7	
51-201	230	338	384	420	457	388	48.7	14	.5	.10	2	4	10.8	.164	308	8.8	8.0	7.9	6.9	6.9	-	C	---	10	
49-224	364	563	407	442	501	419	25.8	87	5	---	---	---	64.0	.106	456	1.1	.9	---	1.0	1.0	A	-	C	---	14
51-86	175	239	287	348	432	298	55.6	---	---	---	---	---	---	.169	264	1.3	.7	---	1.0	1.0	A	-	-	---	30
50-105	428	474	508	550	601	512	38.4	.18	---	---	---	---	15.6	.158	376	3.8	2.9	---	3.4	3.4	A	-	-	---	13
50-264	152	288	350	413	477	328	47.4	22	8	.58	9	12	18.6	.153	351	9.2	12.8	11.6	10.4	11.0	A	-	C	---	11
51-905	---	---	---	---	---	328	47.4	.22	---	1.40	---	---	---	.153	351	2.3	1.3	2.3	2.4	2.1	A	-	-	---	18
51-228	---	---	---	---	---	328	47.4	22	---	.37	95	103	---	.183	351	1.4	1.8	1.8	1.6	1.6	B	-	-	---	8
48-279	164	273	370	437	501	349	44.1	26	12	.04	8	17	24.6	.150	347	3.3	2.5	2.9	2.9	2.9	A	-	-	---	9
48-393	158	271	370	436	502	347	43.6	28	---	.58	10	16	---	.180	347	7.5	6.5	7.1	7.0	7.0	A	-	-	---	12
48-361	160	270	369	437	500	347	43.6	---	---	1.03	7	16	---	.150	347	19.0	21.8	19.7	20.2	20.2	-	D	-	---	5
48-162	158	270	368	432	500	344	45.2	28	12	.04	6	16	24.8	.150	348	11.4	15.0	---	13.2	13.2	-	E	-	---	6
50-122	---	---	---	---	---	344	45.2	28	---	1.05	---	---	---	.150	348	8.5	9.1	---	8.8	8.8	-	D	-	---	3
49-71	182	312	398	484	515	372	44.9	32	---	---	---	---	---	.154	348	21.7	21.8	---	21.7	21.7	-	E	-	---	3
49-72	220	351	420	463	515	383	43.2	34	54	---	7	31	---	.158	336	8.0	8.7	---	8.4	8.4	-	D	-	---	4
49-125	175	307	383	462	512	367	44.5	30	---	---	77	445	---	.154	340	3.0	2.7	---	2.5	2.5	-	D	-	---	4
49-143	181	318	397	468	517	376	43.2	22	25	---	168	580	---	.154	344	23.2	21.7	---	22.5	22.5	-	E	-	---	3
49-65	221	358	438	518	535	268	45.4	33	67	---	5	337	---	.142	345	5.1	5.8	5.8	6.0	6.0	-	F	-	---	5
																6.7	6.3	---	6.5	6.5	-	F	-	---	3
																13.9	11.3	---	12.6	12.6	-	G	-	---	10
																12.1	14.5	---	13.5	13.5	-	G	-	---	9
																15.6	13.8	---	14.7	14.7	-	G	-	---	6
																15.2	17.8	---	15.4	15.4	-	G	-	---	14
																14.0	16.8	---	15.4	15.4	-	G	-	---	9

*Reference 10.

*Reference 4.

*Reference 1.

*Table I.

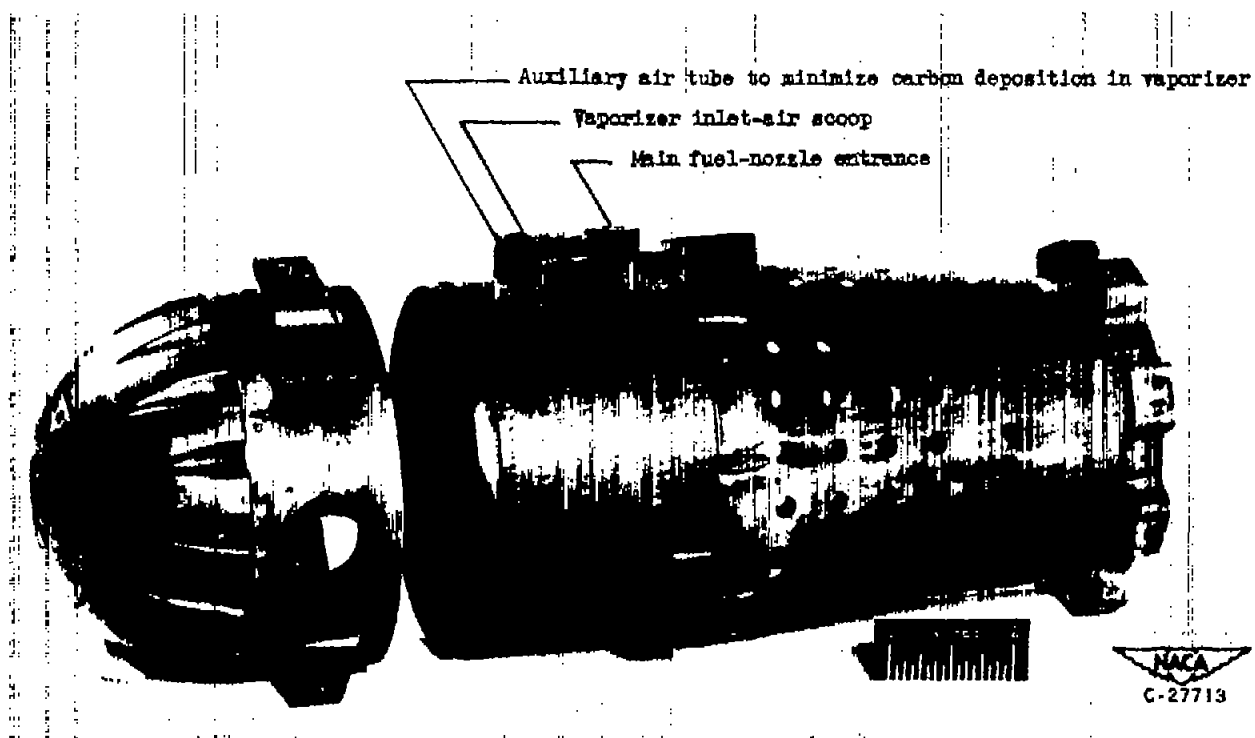
*Arithmetical average percent variation of individual carbon deposit values from arithmetical average deposit value.

*Silica gel.

*Estimated.

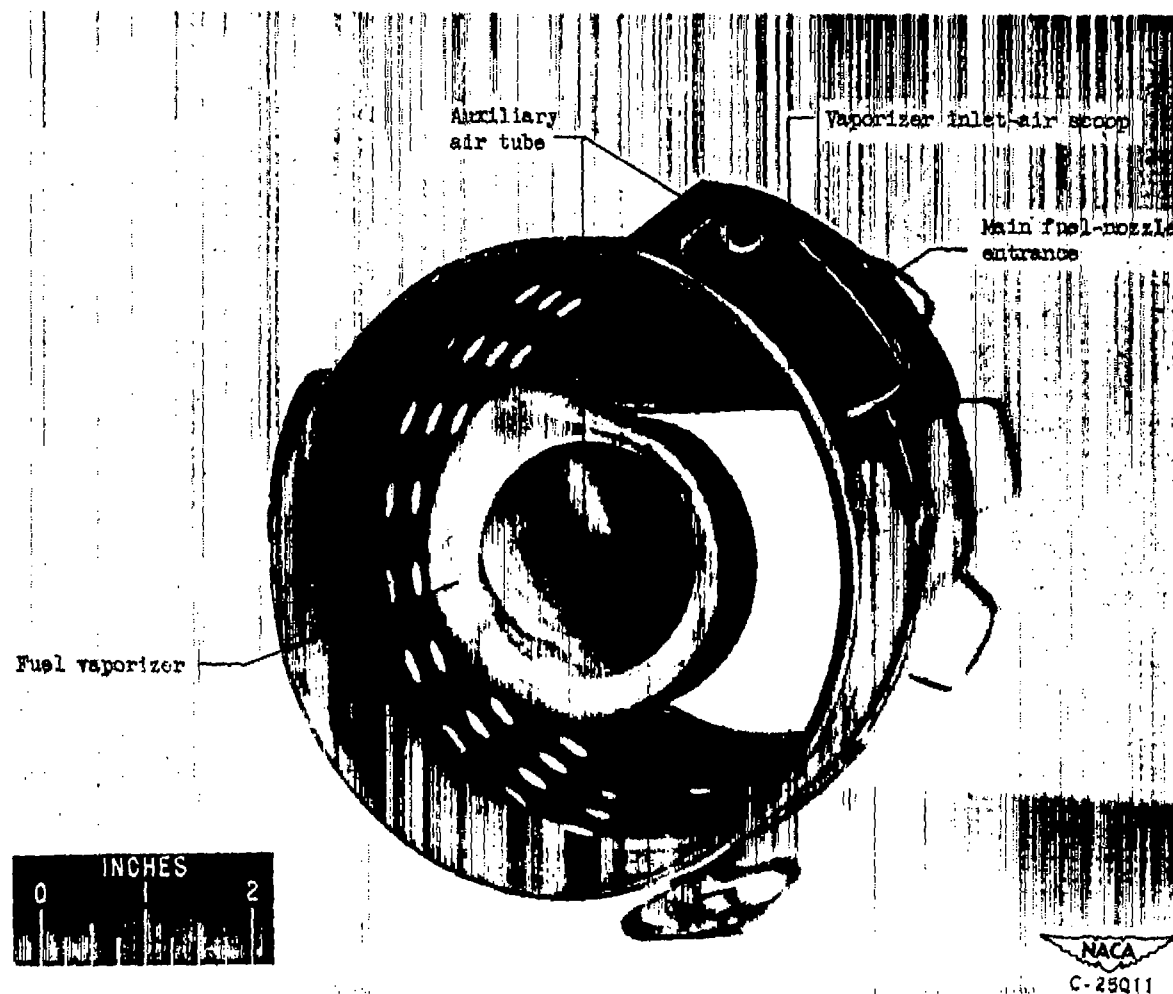
*Includes two starts.

NACA



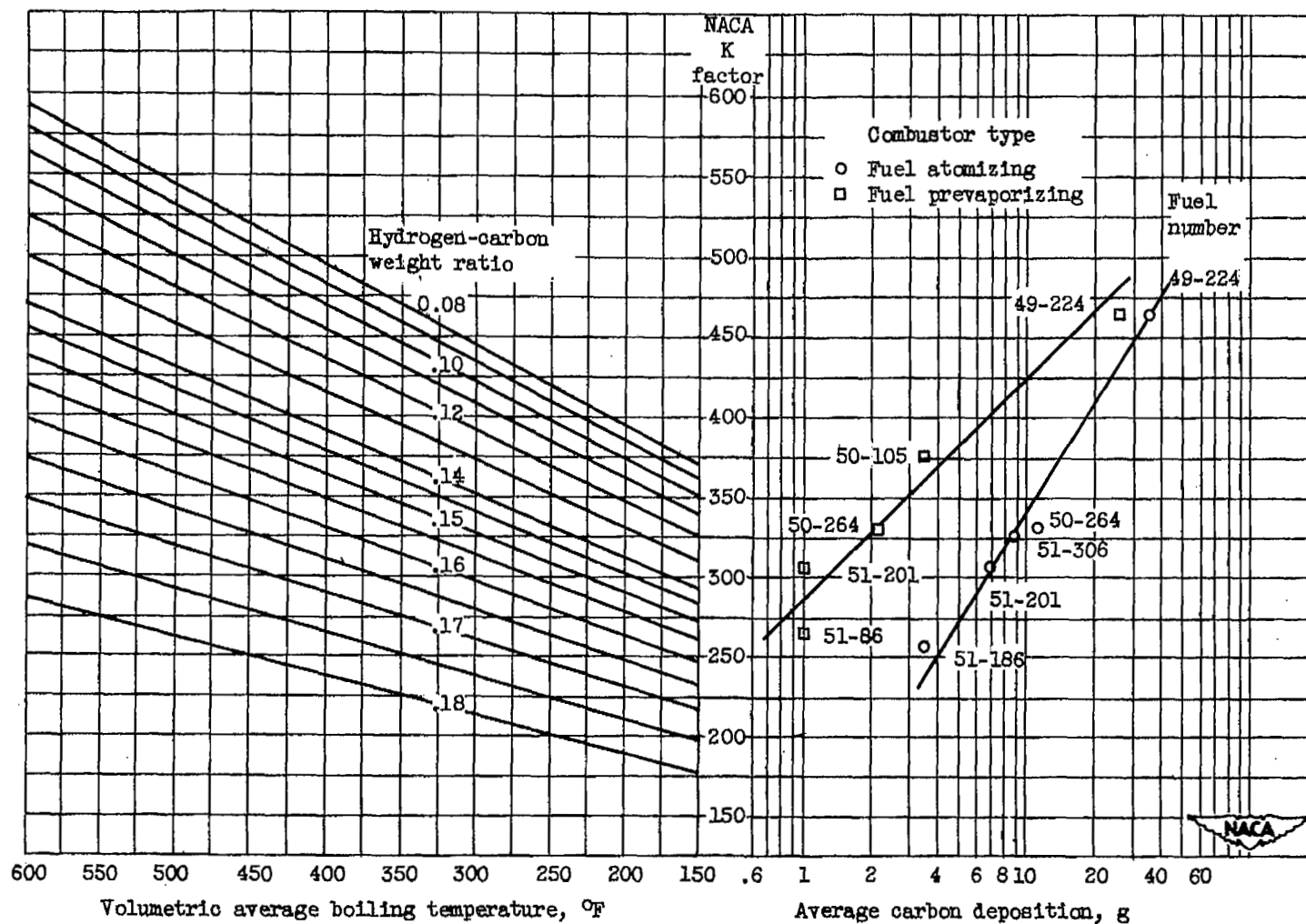
(a) Combustor inner liner showing vaporizer inlet-air scoop and auxiliary air tube.

Figure 1. - Fuel-prevaporizing combustor.



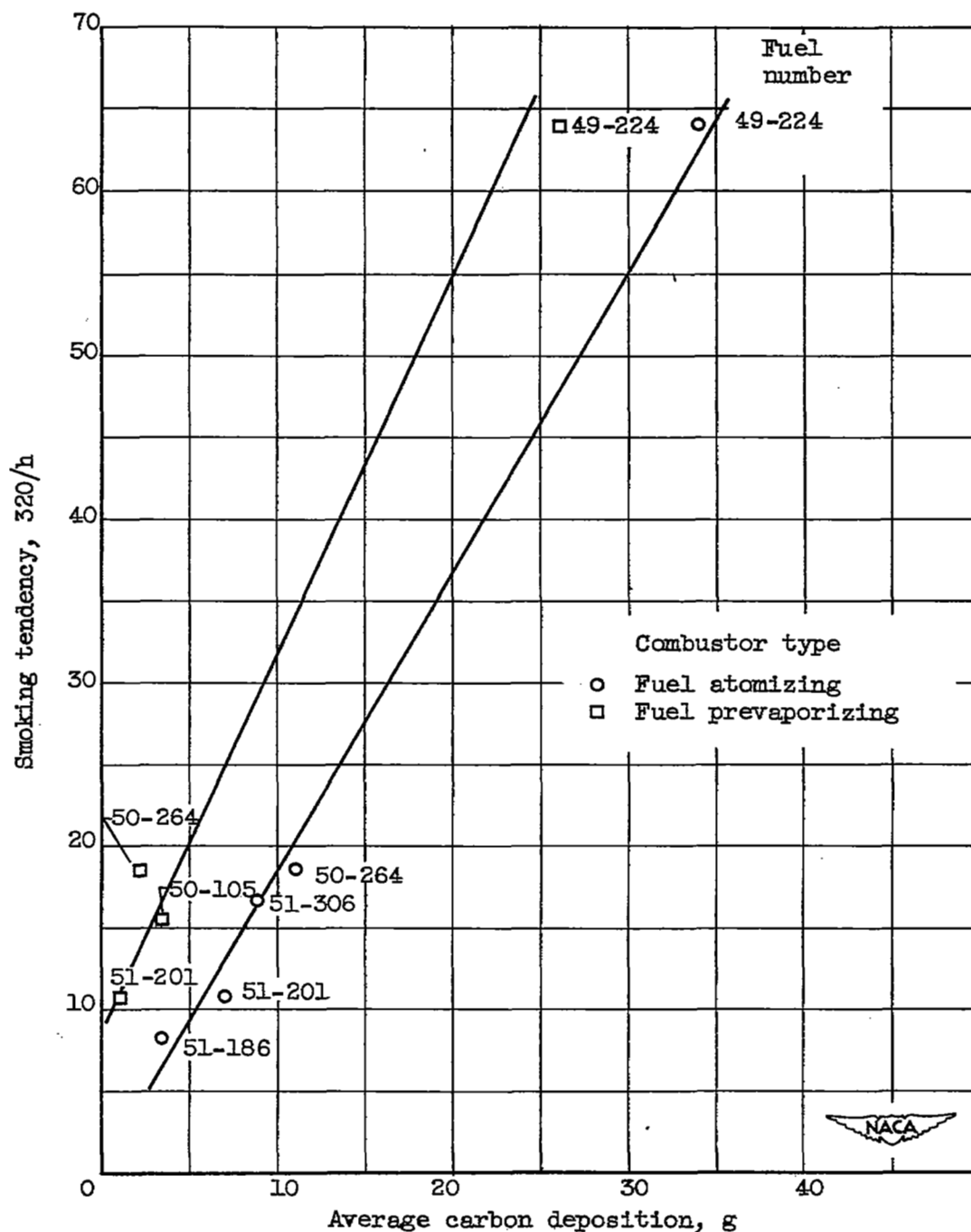
(b) Part of inner liner showing fuel vaporizer, vaporizer inlet-air scoop, and auxiliary air tube. Downstream view.

Figure 1. - Concluded. Fuel-prevaporizing combustor.



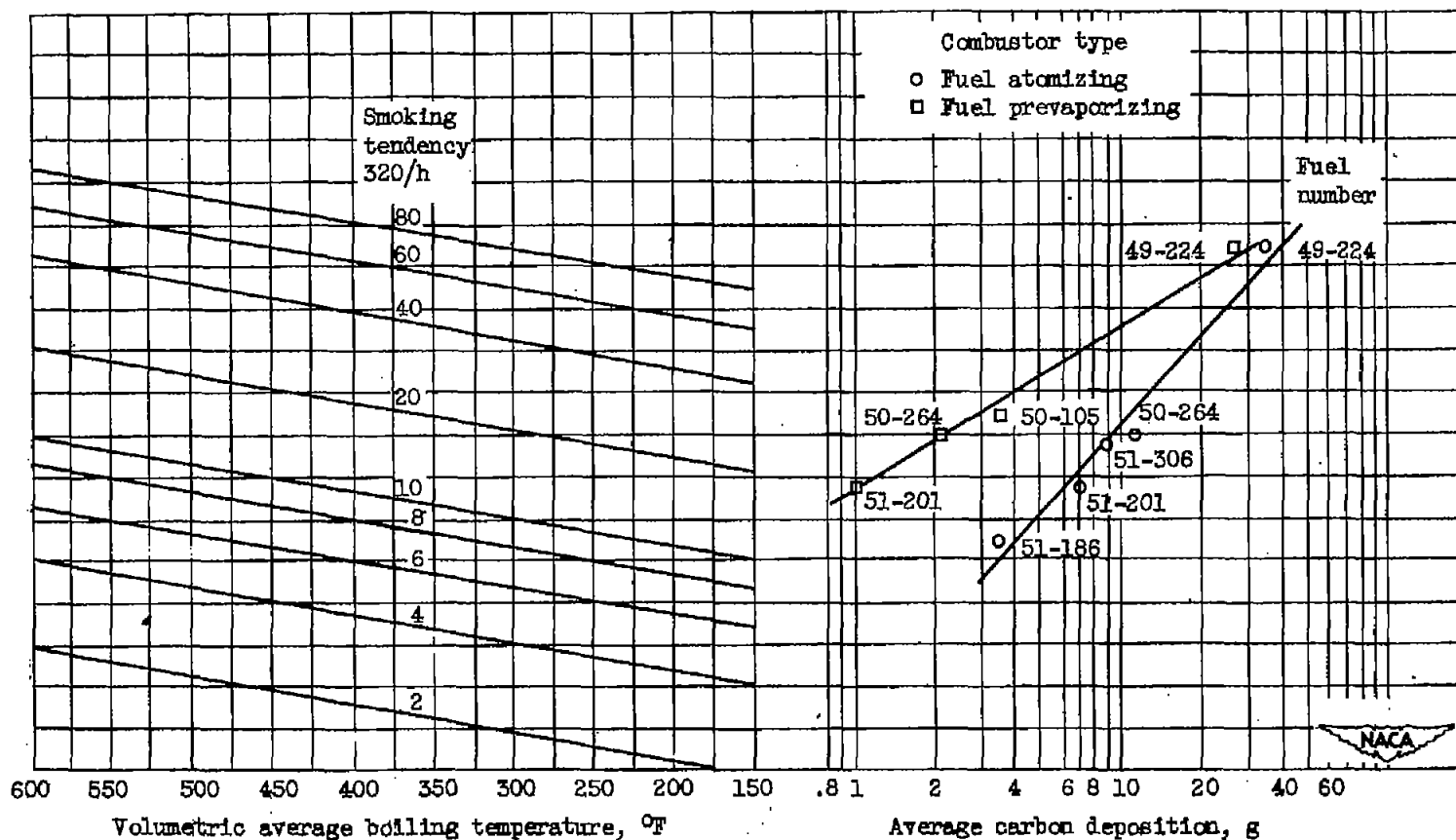
(a) Volumetric average boiling temperature and hydrogen-carbon ratio.

Figure 2. - Carbon deposition of several fuels obtained in two types of single combustor related to various correlation functions. Engine conditions A and C (table I).



(b) Smoking tendency.

Figure 2. - Continued. Carbon deposition of several fuels obtained in two types of single combustor related to various correlation functions. Engine conditions A and C (table I).



(c) Smoking tendency and volumetric average boiling temperature.

Figure 2. - Concluded. Carbon deposition of several fuels obtained in two types of single combustor related to various correlation functions. Engine conditions A and C (table I).

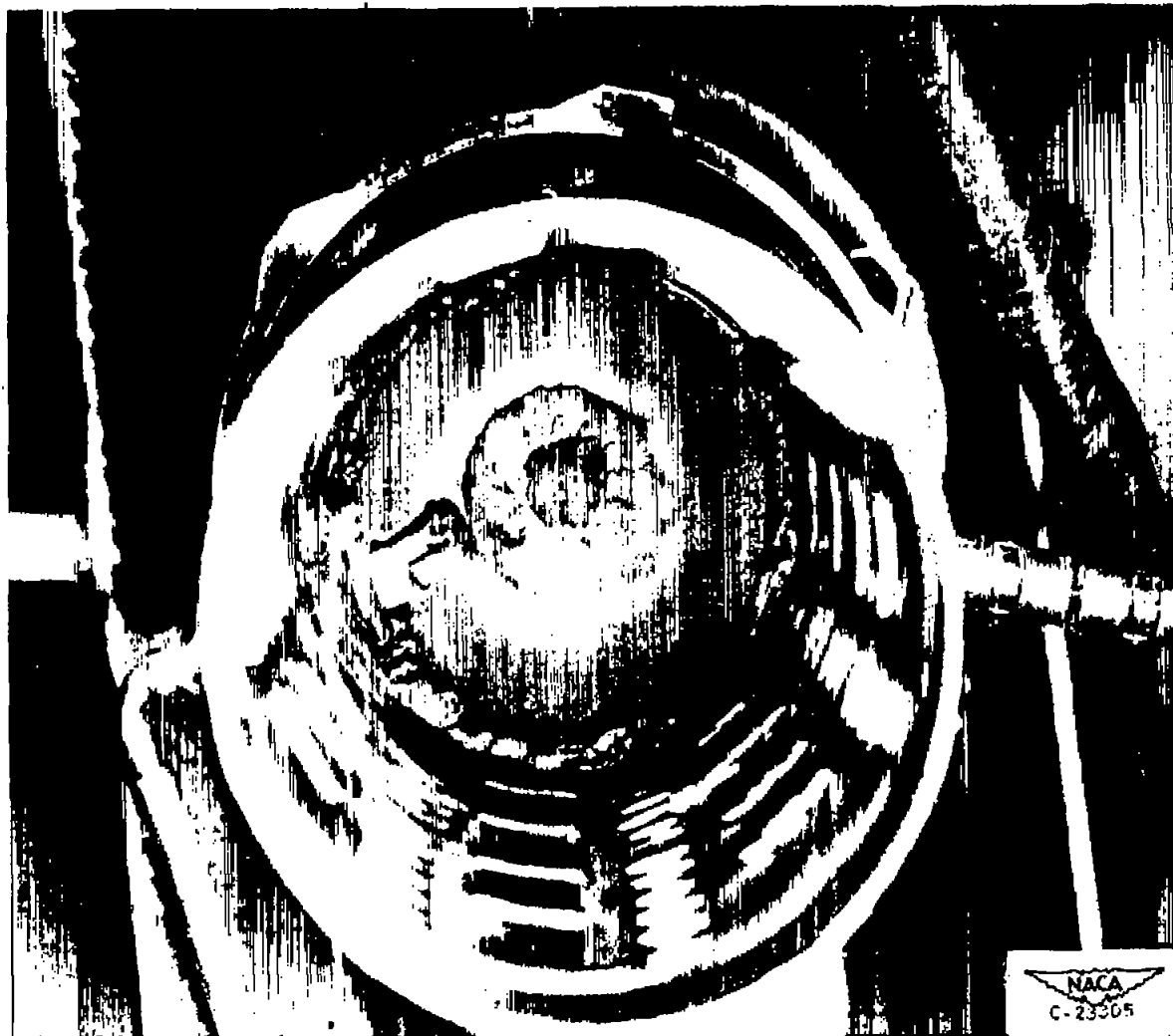


Figure 3. - Fuel-atomizing combustor liner. Upstream view.

SECURITY INFORMATION

[REDACTED]



[REDACTED]

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